MULTIBODY DYNAMICS SIMULATION AND EXPERIMENTAL INVESTIGATION OF A MODEL-SCALE TILTROTOR

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OBJECTIVE

The objective of this investigation is to develop a multibody analytical simulation model to predict the dynamic response, aeroelastic stability, and blade loading of a soft-inplane tiltrotor wind-tunnel model and correlate that with experimental data. A Joint Vertical Aircraft Task Force is currently developing requirements to meet Army and Navy needs for a heavy lift transport rotorcraft that is expected to include, at a minimum, a 20-ton payload lift capability. Development of soft-inplane tiltrotor technology is beneficial for providing viable lightweight hub design options for this future application. Experimental testing, either in flight testing or with a wind tunnel test article, is becoming prohibitively expensive. Advanced simulation and modeling of these complex tiltrotor hub configurations using multibody dynamics codes may prove to be an alternative to such expensive experimental verifications in the future. The use of multibody dynamics codes to predict and reduce the risk of encountering aeromechanical instabilities and adverse loading situations for a soft-inplane tiltrotor hub design is detailed in this investigation. Comprehensive rotorcraft-based multibody analyses enable simulation and modeling of the rotor system to a high level of detail such that complex mechanics and nonlinear effects associated with control system geometry and joint free-play may be considered. The influence of these and other nonlinear effects on the aeromechanical behavior of the tiltrotor model is examined. A parametric study of the design parameters which influence the aeromechanics of the soft-inplane rotor system is also included in this investigation.

APPROACH

A new four-bladed semi-articulated soft-inplane (SASIP) rotor system, designed as a potential candidate for future heavy-lift rotorcraft, was tested at model scale on the Wing and Rotor Aeroelastic Testing System (WRATS), a 1/5-size aeroelastic wind-tunnel model based on the V-22 (Fig. 1, Nixon, et. al., 2003). The experimental part of this investigation included a hover test in helicopter mode subject to ground resonance conditions, and a forward flight test with the model in airplane mode subject to whirl-flutter conditions. A three-bladed stiff-inplane gimballed rotor system, used in several previous experiments, was examined under the same conditions as the four-bladed soft-inplane hub to provide a baseline for comparison.

Detailed analytical models of the SASIP tiltrotor have been developed using the multibody dynamics rotor code known as DYMORE (Fig. 2, Bauchau, 1998). The multibody analysis includes dynamic models for parts of the rotor system which are often not considered in classical rotor analyses, such as the hydraulic actuator control system, the swashplate mechanics (rotating and non-rotating components), pitch links, pitch horns, the rotor shaft and the hub kinematics. The rotor blades are modeled as elastic beams undergoing coupled flap, lag and torsion deformation similar to the finite element methods used in classical rotorcraft analyses. An analytical model of the SASIP tiltrotor has also been developed using a classical rotorcraft analysis known as UMARC/G, and is based on the UMARC (Bir and Chopra, 1991) rotor code. This analysis does not have the capability to model complex joints and extreme nonlinear behavior as do the multibody codes, but is useful to serve as an analytical standard for some portions of the current study.

KEY RESULTS

Several multibody dynamics simulations and experiments using the SASIP rotor system and its subcomponents have been conducted. The key simulations and data correlations included in this paper are: 1) an isolated blade for elastic mode comparison, 2) a control system kinematic simulation, 3) a hover stability simulation, 4) an airplane mode

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whirl flutter stability boundary determination, and 5) simulation of free-play in the rotor hub and its effects on aeromechanical stability predictions.

Key results of this investigation are that a multi-body dynamics model has been developed for this investigation that includes the rotor blades, pitch link, swashplate, and hydraulic control actuators which are attached to the pylon, and an elastic wing that is modeled using finite elements. For the SASIP four-bladed rotor system the rotor blades, hub joints, and the control system have been also developed. The DYMORE model of the SASIP rotor also includes free-play in the model transmission, which is a highly non-linear effect (Fig. 3).

A comparison of elastic blade frequencies, for the condition of an isolated blade mounted to the hub has been completed. The results indicate consistent capabilities of modeling the elastic blade and hinge dynamics among the analyses and generally good agreement with the experimental results. Mode shape comparisons of the three analyses for the fourth mode are excellent and are of particular interest because this mode has significant participation from flap, lag, and torsion. The nonlinear modeling capability of the multibody codes is also investigated, including simulation of free-play in the model rotor transmission. The presence of free-play in the experimental model led to unacceptably low damping in airplane mode and consequently a very low stability boundary. A parametric study of rotor lag damping will also be completed as part of this investigation, which may help to determine suitable design criteria for future soft-inplane tiltrotor systems.

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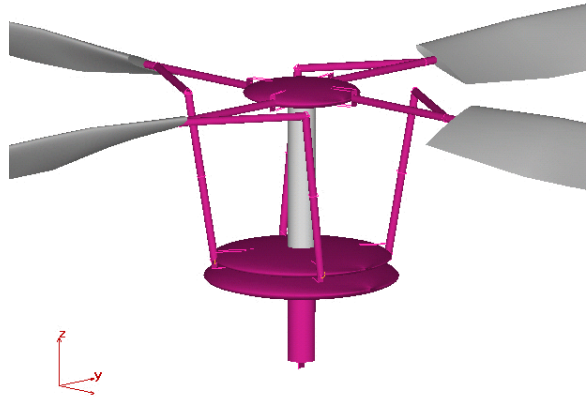
Figure 1: Soft-inplane Tiltrotor Model in TDT.
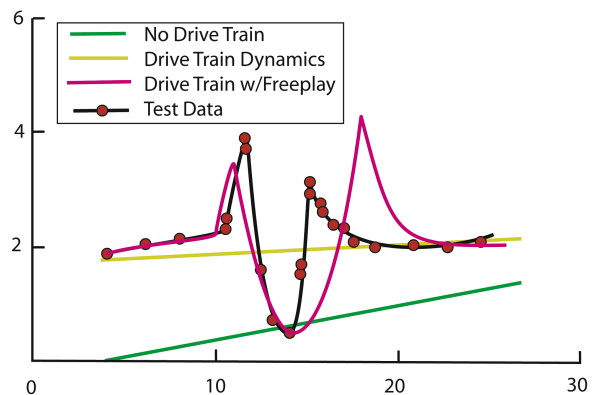

Figure 2: DYMORE model of soft-inplane rotor.

Figure 3: DYMORE damping estimation with free-play.